AD-A049 739 SACHS/FREEMAN ASSOCIATES INC HYATTSVILLE MD F/G 20/3

IEMCAP IMPLEMENTATION STUDY. VOLUME I.(U)

DEC 77 E FREEMAN F30602-76-C-0356

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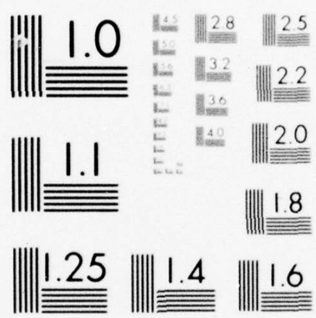

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RADC-TR-77-376, Volume I (of two)
Final Technical Report
December 1977

IEMCAP IMPLEMENTATION STUDY

E. Freeman

Sachs/Freeman Associates

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ROME AIR DEVELOPMENT CENTER
Air Force Systems Command
Griffiss Air Force Base, New York 13441

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(19) REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER (18) RADC-TR-77-376, ~~Vol I (of two)~~ VOL-1	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) (6) IEMCAP IMPLEMENTATION STUDY. Volume I.	5. TYPE OF REPORT & PERIOD COVERED (9) Final Technical Report.
	6. PERFORMING ORG. REPORT NUMBER N/A
7. AUTHOR(s) (10) E./Freeman	8. CONTRACT OR GRANT NUMBER(s) (15) F30602-76-C-0356 new
9. PERFORMING ORGANIZATION NAME AND ADDRESS Sachs/Freeman Associates, Inc 7515 Annapolis Rd - Suite 408 Hyattsville MD 20784	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS (16) 62702F 45400138 (17) 01
11. CONTROLLING OFFICE NAME AND ADDRESS Rome Air Development Center (RBCT) Griffiss AFB NY 13441	12. REPORT DATE (11) December 1977
	13. NUMBER OF PAGES 54
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Same (12) 64p.	15. SECURITY CLASS. (of this report) UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

DDC RECEIVED FEB 10 1978 B

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Same

18. SUPPLEMENTARY NOTES

RADC Project Engineer: James C. Brodock (RBCT)

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Electromagnetic Compatibility
Intrasystem Analysis

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report addresses the need for an intrasystem analysis in the development of a new or modified weapon system. A survey was first performed to determine the current implementation of the EMC process in a weapon system's development. The results of this survey are presented. The economics of using a computerized intrasystem analysis was also examined. This report covers the costs associated with installing and using an analysis system and the cost reduction benefits derived from its utilization. over

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The five phases of the acquisition life cycle are also examined with recommendations made concerning the extent of intrasystem analysis appropriate for each.

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IEMCAP IMPLEMENTATION EFFORT

FINAL REPORT

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Executive Summary

This study was performed for the purpose of determining how the Air Force developed Intrasystem Electromagnetic Compatibility Analysis Program (IEMCAP) could best be implemented in the USAF weapons system procurement process. This purpose was somewhat broadened to include the entire Intrasystem Analysis Program (IAP). The procedure employed was to perform an extensive literature search and structured interviews to determine the current procedures and methodology. Analysis of the results lead to conclusions and recommendations and a proposed handbook.

The following is a list of the major conclusions and recommendations of the study.

1. Adequate contractor support requires inclusion of IAP requirements in contractual documents. Methods for accomplishing this are included in the handbook.

2. Sufficient data for supporting IAP requirements are available early in the procurement cycle.

3. The major cost saving area for the use of IAP appears to be in system test planning.

4. Specification tailoring through the use of IAP is a desirable goal but requires a cautious approach until more experience and results are available.

5. The IAP is best applied at the prime contractor level.

6. A central intrasystem compatibility analysis program facility is required for supporting the project management community.

7. Seven USAF documents should be changed as recommended in this report.

8. The IAP should be run, as a minimum, at the time of the development of the EMC Control Plan, at the Preliminary Design Review (PDR), at least once before Critical Design Review (CDR), at CDR, and for the system test plan.

9. The minimum size criterion for the application of IEMCAP is for systems of 100 or more possible EM interactions (combinations of emitters, receptors and ports).

10. Waiver and deviation requests and Engineering Change Proposals (ECP's) where EMC may be affected should be accompanied by an appropriate IAP analysis.

11. The system procurement EMC handbook contained herein should be implemented. Its use and adequacy should be reviewed after a suitable period of time, such as one year, and then modified as appropriate.

12. A user handbook for the implementation of the IAP, as a group of programs, should be developed.

EVALUATION

The objectives of this effort were directed to the following areas.

(1) What type of data is available at the different stages of the weapon system acquisition process?

(2) How much will the data need to run IEMCAP cost?

(3) What data items should be included in the procurement package?

(4) How will the tailoring of specifications affect the prime contractor-subcontractor relationship and the prime contractor-Government relationship?

(5) How will testing be impacted by this analysis?

The objectives were obtained. Sachs/Freeman examined each area thoroughly, summarized the results, and made recommendations on the applicability of an IEMCAP analysis to various size programs. Through a handbook, Sachs/Freeman has provided guidance on applying the Air Force Intrasystem Analysis Program to Air Force System Procurements at all phases of the life cycle.

The results of this effort will be widely distributed. Attempts will be made to make the handbook an official Air Force handbook. In the interim, it is suggested that the Program Offices use the unofficial handbook as a guide to their EMC programs.

James C. Brodock

JAMES C. BRODOCK
Project Engineer

IEMCAP IMPLEMENTATION EFFORT

Final Report

I. GENERAL

1. Introduction

This section will describe the scope of this project, the procurement process that it supports, and pertinent EMC tools and techniques. The role of EMC analysis in the weapons system procurement process is presented. The content and utilization of intrasystem EMC analysis programs are discussed.

2. Objective & Background

The objective of this effort is to obtain information on data availability, costs, revisions to Contract Data Requirements List (CDRL) items, analysis cost impacts, additions to contractual specifications and statements of work, and other factors pertinent to the application of the Intrasystem Electromagnetic Compatibility Analysis Program (IEMCAP) to new weapon system procurements. The purpose of this report is to document the results of the project. This first phase was intended to review the system development process and the IEMCAP concept and to gather data concerning the use of IEMCAP and related techniques in the system acquisition process emphasizing the management aspects. One method used for assessing the role of computer based EMC analysis was a series of meetings with a structured format. The subjects pursued included the organization of the EMC effort, its place in the management structure, support requirements for IEMCAP, scheduling and costs of running IEMCAP, the uses of the outputs and possible other uses of

the data base. The second phase was to follow-up on the results of the first phase by developing modifications to documents, suggested IEMCAP and the Intrasystem Analysis Program (IAP) scheduled, cost-benefit trade-off data, and general project management guidance for the implementation of the IAP.

3. The Five Phases of the Acquisition Life Cycle

The acquisition life cycle consists of five phases: conceptual, validation, full-scale development, production and deployment. This regime is described in AFSCP 800-3. Significant aspects of this process are specific DoD policy guidelines. Among these are:

(a) flexibility in the selection of the strategy or technique to be used for any given system development;

(b) emphasis on hardware development during concept formulation to reduce technical risks;

(c) incremental independent development of subsystems and components in the initial stages of major system developments; and

(d) the introduction of multiple decision points during the development and acquisition of new systems.

The five phases of the acquisition life cycle represent a formalized procedure not always fully utilized for all programs. Specific programs may skip phases and various program elements may be in any or all phases at any time.

3.1 Conceptual Phase

The first phase is the Conceptual Phase. Technical military and economic bases for an acquisition program are established in this phase. Included are definitions of operational capability, doctrine, and specific material requirements. Performance characteristics may be established only

in very general terms. Critical technical and operational issues are identified for resolution in subsequent phases. The outputs of this phase are alternative concepts and their characteristics, estimated operational schedules, and procurement costs and support parameters.

These planning documents provide the first opportunity for the consideration of EMC. Preliminary selection of the frequency band, modulation and other principle technical characteristics of the system are required in the case of C-E equipment. An application for an experimental frequency allocation is also required. For systems and equipments not specifically designed to utilize the RF spectrum, a determination of system technical characteristics is needed to evaluate and establish controls on potential mutual interference. The EMC activities are primarily concerned with determining the occupancy of frequency bands, required bandwidths, application of appropriate specifications and standards, and in developing an estimate of EMC feasibility as an input to the first decision point. The organization of an EMC Advisory Board and the development of an EMC Program may be desirable for certain projects.

3.2 Validation Phase

The second phase of the LCSMM is the Validation Phase. In this phase the choice of the alternative is validated. Frequently this phase includes the construction of prototypes to refine costs, environmental impact, and operational and technological factors. Extensive study and analysis, hardware development, testing, and evaluation is devoted to providing a basis for decisions concerning full-scale development.

EMC activities in this phase include preparation of the EMC-related

portions of the equipment performance specifications for the prototypes, development of plans for the EMC portion of development and operational tests, reviewing results of the EMC testing, and verifying that potential EMC problems have been averted or can be expected to be resolved during later phases. At this point frequency and bandwidth requirements are usually in final form, requiring application for a developmental frequency allocation. At this stage an appropriate analysis capability could be applied to tailoring the EMC specifications or standards to provide appropriate EMC protection at the least cost.

3.3 Full-Scale Development Phase

The third phase in the LCSMM is the Full-Scale Development Phase. During this period the system and principle items necessary for its support are fully developed and engineered, fabricated, and tested. The intended output is a minimum pre-production system that closely approximates the final product, the documentation necessary to enter the production phase, and test results that demonstrate that the production system will meet stated requirements. Engineering development contracts are awarded and the second set of development and operational tests is conducted. The program office activity is heavily oriented towards design reviews and the test program. The initial production contract is awarded following the completion of the development and operational tests.

The products of this phase are subjected to a third set of tests. The EMC considerations and actions in this phase include preparation of the EMC part of the equipment development specifications (including generating the limits for the tailored specifications), preparation of the EMC tests

for the second and third test series, and review of the EMC test results. Also included are verification that EMC performance of developmental and initial production equipment is satisfactory and verification that the system or equipment is ready for production from an EMC viewpoint. The operational spectrum allocation application is prepared at this time.

3.4 Production Phase

The fourth phase, Production, encompasses the program from production approval to delivery and acceptance of the last item. EMC activity is concerned with the production specifications, configuration management, engineering change proposals, and system and equipment testing. Category II and III testing is monitored to determine whether latent intrasystem or intersystem EMC problems exist.

3.5 Deployment Phase

The fifth phase, Deployment, begins with the user's acceptance of the first operational unit and extends until the system is phased out of the inventory. There is usually an overlap with the production phase. At times, production and deployment are discussed as one phase.

4. The Industrial EMC Cycle

The view of the EMC engineer or analyst at the industry level is not usually as broad or long-term as the above LCSMM description might imply. One reason is that an individual company or EMC group will not necessarily be involved in the same project over the entire time span. Seen from this level, the work will also be assigned as separate tasks with no guarantee of continuity.

The EMC process at this task level is a cycle that may be repeated many times throughout the LCSMM. The following subparagraphs are an expla-

nation of the procedure.

(a) Review customer requirements. The request for quotation (RFQ) or request for proposal (RFP) is the usual first input. The operational requirements and specifications are analyzed and an EMC program approach and requirements are defined.

(b) Define contractual commitments. Clarify and amend specifications, and determine customer, contractor, and subcontractor obligations and commitments. Then assure data interface and analytical capability, perform trade-offs, negotiate requirements, and finally, establish a schedule.

(c) Prepare Control Plan. Perform EMC frequency and time domain analysis based on system configuration and mission analysis definitions. Define problems and methodology to provide solutions possibly by establishing system/subsystem requirements for design, control and test. Refine the schedule and define an EMC program for the system and each subsystem in enough detail so as to serve as a mangement tool for monitoring and controlling the EMC effort.

(d) Implement EMC Program. Ensure that the analysis, design test and documentation effort defined in the Control Plan is performed as required. Prepare and update data base and take appropriate actions to assure EMC as the program progresses by implementation of the methodology established.

(e) Subsystem test. First, write test procedures, then validate marginal designs/design trade-offs. The final step will be qualification testing.

(f) System tests. Develop and prosecute system tests, then validate system and subsystem compatibilities. Follow-up by evaluating problems, verifying solutions, and documenting results.

Therefore, the procedure, as far as the contractor is concerned, is primarily one of analyzing and verifying EMC conditions within his system in the particular phase in which he is currently involved and taking preventative or corrective action as appropriate. The IAP should be extremely valuable in this activity. The particular portions of the EMC cycle performed, the accuracy requirements, data inputs, and required outputs are a function of the particular life cycle phase. For example, while the use of

tailored EMC specifications might not be appropriate in the validation phase, they may be very appropriate for the production phase.

5. Intrasystem Compatibility Programs

A major objective of this effort is to determine the implementation of IEMCAP (Intrasystem EMC Analysis Program) in the system acquisition process. The objective of IEMCAP is to facilitate the practical implementation of EMC at all stages of an Air Force system's life cycle, from conceptual studies of new systems to field modification of old systems. IEMCAP is a software development similar to three prior intrasystem programs designed for three different applications. One of these was designed for aircraft (ATACAP), one for spacecraft (SEMCAP), and one for ground systems (ISCAP). IEMCAP, in turn, is part of an overall Air Force Intrasystem Analysis Program (IAP) which is composed of the following:

(a) IEMCAP;

(b) a series of supplemental models (for use in conjunction with IEMCAP) that provide additional analysis for aircraft stores, electroexplosive devices and systems, lightning, magnetospheric substorms, and static electricity;

(c) nonlinear and EM/near-field analysis models (which will characterize the input/output relation of nonlinear circuits, EM/near-field interactions, and antenna and aperture coupling) being developed for off-line use;

(d) instrumentation, test, and measurement support equipment;

(e) training courses;

(f) validation/implementation efforts; and

(g) Air Force management (data base).

To put IEMCAP in perspective, it can be viewed alongside other ser-

vice or application intrasystem models which have been or are being developed, parallel with IEMCAP. Examples of these are such programs as SEMCA (Shipboard Electromagnetic Compatibility Analysis) developed by the Navy and designed for the analysis of the electronics mounted on a ship superstructure; and COSAM, (Cosite Analysis Model) an ECAC program based on developing analysis for specific groups of equipments, (e.g., UHF ground-to-air communications, VHF-FM tactical communications). Other programs have and are continually being developed by such organizations as Grumman Aircraft, Litton, the University of Pennsylvania and others.

6. Overview of IEMCAP

A more detailed description of IEMCAP is included in the handbook (Attachment 1). This section is intended to summarize its capabilities to provide a basis for further discussion. IEMCAP is designed to:

(a) provide a data base which can be continually maintained and updated to follow system design changes;

(b) generate EMC specification limits tailored to the specific system;

(c) evaluate the impact of granting waivers to the tailored specifications;

(d) survey a system for incompatibilities;

(e) assess the effect of design changes on system EMC; and

(f) provide comparative analysis results on which to base EMC trade-off decisions.

The basic medium for modeling signals is the frequency domain. Each emitter's emission characteristics are represented basically by its power output, tuned frequency, and spurious emission levels and frequencies (intermodulation is not presently included in the model). The model assumes that harmonic spurious output levels can be approximated by one or more

straight line segments. Spurious output frequencies are determined by the user or as harmonics of the tuned frequency. When applicable they can be generated by the computer code.

The receptor representation is similar to that of the emitter. The receptor characteristics are represented by its sensitivity, tuned frequency, selectivity curve, spurious response levels and spurious frequencies. It is assumed that the spurious response levels can be approximated by one or more straight lines. Spurious response frequencies can be generated by the code. When they are not, the user must determine these frequencies external to the program using available techniques such as the superheterodyne conversion process, etc.

Antenna gains are determined by preprogrammed equations for low gain types. Medium and high gain are represented by multilevel patterns in which each level is specified by a gain and associated azimuth and elevation beam width. Provision is made for three discrete gain levels.

Various models of coupling or transfer functions are included in the program. Filter models used are single tuned, transformer coupled, Butterworth tuned, low and high pass, bandpass and band reject. The filter transfer models calculate the "insertion loss" (in dB) provided by a filter at a given frequency, i.e., the reduction in delivered power due to insertion of a filter.

There are two antenna-to-antenna propagation models available. For ground systems the propagation model is a simplified theoretical ground wave model which assumes a smooth earth surface with a 4/3 earth radius accounting for atmospheric refraction. An intravehicular propagation model calculates the propagation loss associated with an electromagnetic coupling path when

both emitter and receptor are located on the same aircraft or spacecraft. The power received is related to the power transmitted, free space transmission (Friis equation) and a shading factor due to the presence of the vehicle whose bulk may be interposed in the region between emitter and receptor.

Environmental electromagnetic field interaction with the system wiring is determined. External fields enter a vehicle through dielectric apertures in the system's skin and couple onto immediately adjacent wires. The coupled RF energy is a function of the aperture size and location. A transmission line model is then used to compute the currents induced in the wire loads.

Wire coupling between wires in a common bundle considers capacitive coupling due to the interwire capacitance as well as inductive coupling due to the mutual inductances between the wires. The approximation is made that the total coupling can be computed separately. Relatively complex wire configurations [e.g., shielded (single or doubled shield), unshielded, twisted pair, balanced or unbalanced] can be handled.

The equipment case model treats each case as though it were a dipole. The coupling model assumes a fall off of $(1/R)^3$, where R equals the distance between cases, for both the electric and magnetic fields. This agrees with standard EM propagation theory.

The data output contains the level of interference from each source (output port) to each receptor (input port). This may generate a voluminous printout. It also summarizes the total interference in each input port due to the sum of the ouput ports.

7. IEMCAP and Military Standards and Specifications

The major standards and specifications associated with the intrasystem EMC assurance process are as follows:

(a) MIL-STD-461A, 462 & 463: This is the basic set of standards used to control the EMC interface of equipments and subsystems. They cover the requirements and test limits for the measurement and determination of the electromagnetic interference characteristics (emission and susceptibility) of electronic, electrical, and electromechanical equipment. The requirements are applied for general or multi-service procurements and single-service procurements, as specified in the individual equipment specification, or the contract or order.

MIL-STD-461A contains the required limits and levels, MIL-STD-462 contains the test procedures and MIL-STD-463 contains definitions and terminology. Table 1 summarizes the items covered.

The limits established in MIL-STD-461A provide no guarantee that equipments will not cause mutual EMC problems, but are an attempt to arrive at levels that would preclude such situations without incurring prohibitive costs for overprotection. The standard includes provisions for an EMC advisory group.

(b) MIL-E-6051D: This specification outlines the overall requirements for system EMC. It includes control of the system EM environment, lightning protection, static electricity, bonding and grounding. It is applied to complete systems, including all associated subsystems and equipments. It also includes provisions for an EMC advisory board (EMCAB) and requirements for analysis.

(c) MIL-I-6181D: This specification covers design requirements, interference test procedures and limits for electrical and electronic aeronautical equipment to be installed in or closely assocaited with aircraft. The test procedures which are specified cover the following types of tests:

- Interference tests - conducted and radiated tests which measure the magnitude of the interference signals emanating from the equipment under test; and
- Susceptibility tests - conducted, radiated, intermodulation and front-end rejection tests which determine whether an equipment will operate satisfactorily when

TABLE 1

TRI-SERVICE EMI MIL-STD-461A/462 TESTS

Test	Test Identification	Frequency Range	Army	Navy	A.F.
		CONDUCTED EMISSION (CE)			
CE01	DC Power Leads	30Hz-50Hz	Yes	No	No
CE01	AC & DC Power Leads	30Hz-20kHz	NA	Yes	Yes
CE02	AC Power Leads	10kHz-50kHz	Yes	No	No
CE02	Control & Signal Leads	30Hz-20kHz	NA	Yes	Yes
CE03	Control & Signal Leads	30Hz-50kHz	Yes	NA	NA
CE03	AC & DC Power Leads	20kHz-50MHz	NA	yes	Yes
CE04	AC & DC Power Leads	50kMz-50MHz	Yes	NA	NA
CE04	Control & Signal Leads	20kHz-50MHz	NA	Yes	Yes
CE05	Control & Signal Leads	50kHz-50MHz	Yes	NA	NA
CE05	Inverse Filter Method	30Hz-50MHz	NA	Yes	NA
CE06	Antenna Terminal	10kHz-12.4GHz	Yes	Yes	Yes
C307	Power Source Tactical Veh.	1.5MHz-65MHz	Yes	NA	NA
		CONDUCTED SUSCEPTIBILITY (CS)			
CS01	DC Power Leads	30Hz-50kHz	Yes	No	No
CS01	AC & DC Power Leads	30Hz-50kHz	No	Yes	Yes
CS02	AC & DC Power Leads	50kHz-400MHz	Yes	Yes	Yes
CS03	Intermodulation	30Hz-10Hz	Yes	Yes	Yes
CS04	Rejection Undes Sig (2 Gen)	30Hz-10Hz	Yes	Yes	Yes
CS05	Cross-Modulation	3-Hz-10GHz	Na	Yes	Yes
CS06	AC & DC Power Leads	Spike Gen.	Yes	Yes	Yes
CS07	Ant. Input-Squelch Cir.	Impulse Gen.	Yes	Yes	Yes
CS08	Rejection Undes Sig (1 Gen)	30Hz-10GHz	NA	Yes	Yes
		RADIATED EMISSION (RE)			
RE01	Magnetic Field	30Hz-30kHz	Yes	Yes	NO
RE02	Electric Field, Broadband	14kHz-1GHz	Yes	No	No
RE02.1	Electric Field, Narrowband	14kHz-12.4GHz	Yes	No	No
RE02	Electric Field	14kHz-10GHz	No	Yes	Yes
RE03	Spurious & Harmonics	10kHz-40GHz	Yes	Yes	Yes
RE04	Magnetic Field	20Hz-50kHz	Yes	Yes	Yes
RE05	Vehicles & Eng-Driven Equip.	150kHz-1GHz	Yes	Yes	Yes
RE06	Overhead Power Lines	14kHz-1GHz	Yes	Yes	Yes
		RADIATED SUSCEPTIBILITY (RS)			
RS01	Magnetic Field	30Hz-30kHz	Yes	Yes	No
RS02	Induction Field Spike	Spike Only	Yes	No	No
RS02	Mag. Induction Field	Power & Spike	NA	Yes	Yes
RS03	Electric Field	10kHz-400MHz	Yes	No	No
RS03.1	Electric Field	2MHz-12.4GHz	Yes	No	No
RS03.2	Electric Field	.1xf-10f etc.	Yes	No	No
RS03	Electric Field	14kHz-10GHz	No	Yes	Yes
RS04	Electric Field	14kHz-30MHz	No	Yes	Yes

exposed to external interference signals.

(d) MIL-STD-469: Specified here are those engineering design requirements established to control the spectral characteristics of all pulsed systems, especially radars, operating between 100 and 40,000 MHz so as to achieve EMC and to conserve frequency spectrum.

(e) MIL-STD-704A: This standard delineates the characteristics of electric power supplied to airborne equipment at the equipment terminals and the requirements for the utilization of such electric power by the airborne equipment. The purpose of this standard is to foster compatibility between aircraft electric systems and airborne utilization equipment to the extent of confining the aircraft and ground support electric power characteristics within definitive limits and restricting the requirements imposed on the electric power by the airborne utilization equipment.

(f) MIL-STD-1541(USAF): This standard was developed as a composite system specification for space systems. It includes the requirements for equipment level and system level EMC tests. It also includes design requirements tailored to the space environment, as well as management controls for an EMC program. It incorporates parts of MIL-E-6051D, MIL-STD-461, and MIL-STD-462 with numerous additions and modifications. It includes an analysis requirement.

(g) MIL-STD-1542(USAF): This standard is a companion document to MIL-STD-1541 encompassing EMC and grounding requirements for basic facilities and equipment including air conditioning, lighting, etc.

Many of these specifications and standards cover the same parameters and are applied to the same equipments but contain different limits or levels. As an example, Notice 3 of MIL-STD-704A (11 April 1973) modifies the spike limits for Air Force procurements by extending them to both AC and DC power. The CS06 limits of MIL-STD-461A now apply to both AC and DC power lines. MIL-E-6051D requires that spike amplitudes be suppressed 6 dB below equipment thresholds. The combination of requirements of MIL-STD-704A and

MIL-E-6051D are not necessarily consistent with the requirements of MIL-STD-461A. In such cases the most stringent requirements usually apply.

The technical relationship of the specifications and standards discussed, in IEMCAP or any intrasystem compatibility analysis program, can be categorized in four ways:

(a) The analysis can be used to develop or modify tailored specifications for the specific system.

(b) The analysis can be used to determine whether the system will meet certain system level specifications such as MIL-E-6051D.

(c) The analysis can be used to determine the relationship between specifications, such as the case of MIL-STD-704A and MIL-STD-461A discussed above, although IEMCAP does not specifically do this.

(d) The analysis can use specification limits as a model parameter to determine system compatibility. For example the use of MIL-STD-461A limits to determine system EMC problems.

The first area discussed, the tailoring of specifications and standards is an optional feature of both IEMCAP and SEMCAP. Any of the other intrasystem models could also be used this way but the systems do not specifically address this function. The second area, known as "baseline analysis" in IEMCAP, is simply a systems analysis with outputs consistent with the parameters of the specification to facilitate comparisons. The third area, the comparison of standards, is done by many intra-system programs. One example is ISCAP, where separate subroutines for analysis of MIL-STD-469 and MIL-STD-188B were included. This, along with the optional use of MIL-STD-461 limits as model parameters, allows for level comparisons. The fourth area, the use of the MIL-STD levels as a data recovery technique is also a feature of many programs, e.g., when design or measured data

is not available the specified limit data is substituted. MIL-STD-461A is used in ISCAP. IEMCAP uses MIL-STD-461A and MIL-I-6181D. The use of these standards is a function of their degree of applicability to the specific system of concern.

7.1 Specification Generation

One of the objectives of IEMCAP is to assist design and EMC engineers in developing EMC specifications such that the system will operate in a compatible mode. The present method of incorporating EMC considerations into system design consists of applying rigid limits such as those in MIL-STD-461 to the individual equipment/subsystem which comprise the total system. Compliance with these limits is insured by testing these units in accordance with MIL-STD-462. General design guidelines are provided to contractors in such documents as AFSC Handbook DH 1-4. The system integration contractor is also tasked by MIL-E-6051D to develop a system EMC plan. This plan defines the contractor's overall EMC program and emphasizes the incorporation of EMC considerations during initial design. Included as a part of this program are extensive system tests to insure system EMC before deployment.

IEMCAP includes a capability for specification generation, i.e., developing a tailored specification. This is done as follows: [21]

(a) The first event is the adjustment of the emitters. This is done on a one to one basis. One of the M emitters is chosen and analyzed against one of the N receptors. The analysis is performed and is based upon the linear relationship for power coupled from an emitter, through a transfer medium, and received by a receptor. The general communication theory equation relating power spectral density present at an emitter's output port is expressed as follows:

$$\text{o.p.s.d.} = n_{S_j}(f)\ T_{ij}(f)\ B_i(f)$$

where

o.p.s.d. = output power spectral density (in watts/Hz) received by receptor i (at its detector) from emitter j,

$n_{S_j}(f)$ = output power spectral density (in watts/Hz) at the terminals of source j (including cw power as delta functions),

$T_{ij}(f)$ = power transfer function of the coupling medium between source j and receptor i,

$B_i(f)$ = receptor response function relating power at the detector to power at the input terminals.

If the o.p.s.d. is greater than the receptors susceptibility level, which is described by the receivers response function, then the $n_{S_j}(f)$ is reduced until either o.p.s.d. is less than the receptor's susceptibility level or $n_{S_j}(f)$ has reached its adjustment limit. This adjustment procedure is performed for this emitter and receptor pair for all of their common frequency range and if the frequency in question lies within the unrequired range of the emitter port. If the frequency is within the required range of the emitter no adjustment is performed. This is repeated for each of the N receptors. The IEMCAP chooses another of the (M-1) emitters and performs the smae procedure on a one to one basis with the same N receptors. This continues until all M emitters have been analyzed and adjusted to all N receptors.

(b) The second event is the adjustment of the receptors. This is done on a M to one basis. One of the N receptors is chosen and analyzed against all (m) of the emitters at the frequencies describing its receptor port spectra. If

$$\sum_{i=1}^{M} (\text{o.p.s.d.})_i \text{ is greater}$$

than the receptors susceptibility level, then the $B_i(f)$ is increased until either

$$\sum_{i=1}^{M} (\text{o.p.s.d.})_i \text{ is less}$$

than the susceptibility level or $B_i(f)$ has reached its adjustment limit. This adjustment procedure is performed for this receptor through its frequency range and if the frequency in question lies within the unrequired range of the receptor port. Like the emitter adjustment, if the frequency is within the required range of the receptor, no adjustment is performed. This procedure is repeated on a M to one basis until all N receptors have been analyzed and adjusted.

IEMCAP also calculates an integrate EMI margin which is an overall figure of merit representing the ratio of the power received by the receptor to susceptibility over the entire frequency range. The program computes the margin per bandwidth at all spectrum sample frequencies (both emitter and receptor). For broadband emissions, the received signal is the power contained in one receptor bandwidth. This level is compared to the power required to produce a response in the receptor at the sample frequency. This ratio per bandwidth is integrated over the range of frequencies to obtain the broadband component of the integrated margin.

For narrowband emissions, the power received is independent of the receptor bandwidth, and the integral becomes a summation. The narrowband signal can be represented by one delta function in the center of the receptor bandwidth. The narrowband spectra are limits in that no single delta function can exceed the specified level. If a measuring instrument is connected to this port and tuned across the band, the program assumes that the instrument reads exactly this specification level everywhere. This is equivalent to having one delta function per instrument bandwidth across the band with amplitudes at the spectrum level. These narrowband levels are assumed to vary linearly from sample point to sample point for the summation. The integrated EMI margin is the sum of the broadband and narrowband components.

II. SUMMARY OF SURVEY

1. Introduction

One of the central features of the initial phase of the effort was to determine the actual implementation of the EMC process in the weapons systems development process. As a partial means of satisfying this requirement, a series of interviews was scheduled. These were structured interviews

using a preplanned format. This section discusses the results of that survey.

The visit schedule accomplished during the first phase of the effort is contained in Table 2. The purpose of these visits was to gather data concerning the present and future use of IEMCAP for the organizations contacted and to discuss suggestions for its integration into the procurement process. The specific responses and comments of the individual organizations are available in the SFA project file.

2. EMC and Corporate Organization and Management

The reason for looking into the area of the placement and organization of the EMC function was to determine whether sufficient continuity of staffing would exist to assure adequate maintenance and understanding of a program such as IEMCAP. Such searching will also determine the visibility of the EMC function. Another area of interest was the credibility of EMC analysis results in regard to the various levels of management.

The results of the discussions showed a universal acceptance of the EMC functional area as an integral part of a matrix organization. EMC specialists are assigned as needed to specific projects but continue to be identified as EMC staff. The organizations that have had a part in developing EMC analysis models as end products in themselves, either for governement or commercial users, were much more functionally oriented. That is, they tended to centralize the EMC function more. Those that were not involved in EMC modeling for other than their own use were more project-oriented. In some of these latter cases, it is doubtful that the EMC staff would be able to support and maintain an IEMCAP-type capability due to minimal staffing and cross-transfers of personnel into other technical areas. One key to pro-

TABLE 2

Date	Organization	Personnel
9 August 1976	McDonnell-Douglas Corp. St. Louis, Mo.	G. Weinstock R. E. Plummer
10 August 1976	RAND Corp. Santa Monica, Cal.	A. Hiebert
10 August 1976	General Dynamics Corp. San Diego, Cal.	R. Hinkel M. Derr
11 August 1976	Hughes Aircraft Corp. Los Angeles, Cal.	S. Sabaroff Y. Sheets M. Malinic R. Stroup
11 August 1976	SAMSO Los Angeles, Cal.	Lt. Col. J. Brown Lt. Col. N. McGuiness
11 August 1976	Rockwell Corporation Seal Beach, Cal.	E. Hughes
12 August 1976	Rockwell Corporation (B-1 Office) Los Angeles, Cal.	R. Abernathy
12 August 1976	TRW Corp. Los Angeles, Cal.	B. Cooperstein
13 August 1976	IUS SPO Los Angeles, Cal.	Cpt. Caro
13 August 1976	Aerospace Corp. Los Angeles, Cal.	C. Pearlston J. Coge
13 August 1976	DSCS SPO Los Angeles, Cal.	Cpt. Garrett Cpt. Brown R. Austin C. Kelly P. Sheldon
13 August 1976	GPS SPO Los Angeles, Cal.	Cpt. Ihle Cpt. Rennard
31 August 1976	G.E. Aerospace Valley Forge, Pa.	G. Condon D. Peden D. Ling M. Massaro
13 September 1976	Atlantic Research Corp. Alexandria, Va.	W. Duff

TABLE 2 CONT'D

Date	Organization	Personnel
15 September 1976	Boeing Aircraft Corp. Seattle, Wash.	D. Holtman

viding a sufficient and continuing EMC staff is to provide the proper incentives to corporate management. In the case of the EMC model developing organizations, the new product aspect is a powerful incentive. In other organizations the proper contractual instruments and incentives (in the form of bidding advantages due to a strong EMC capability) will have to be factored in to provide a strong EMC functional center.

Other organizational differences also appear to have potential impact on IEMCAP implementation. Where the EMC specification compliance and test areas are isolated from design, there appears to be an attitude of achieving EMC through repeated test cycles and redesign. In those organizations where the EMC and design groups are separate, there appears to be an adversary situation when the results of EMC analysis are presented. There appears to be a lack of confidence in analysis results when performed by other groups. Measurement results are more readily accepted and, therefore, this separation of EMC and design personnel leads to a heavy reliance on testing. Many of those interviewed felt that the availability and use of IEMCAP (or equivalent analysis) would help this situation. Those who have had the opportunity to use such programs have noted a much higher degree of acceptance of the computer-generated results than those developed by hand calculations. Higher levels of confidence led to less reliance on tests and, therefore, larger cost savings.

3. IEMCAP Data Requirements

The preparation of the required input data for IEMCAP analysis is a subject of inquiry for several reasons. Among these are the costs of preparing the data in relation to present costs, the availability of the

data in relation to desired scheduling of analysis runs, and accuracy requirements. It was a unanimous opinion that the data required for IEMCAP is no different than the data that would normally be used for a comprehensive EMC analysis. This data is normally available from the various design groups, although it has to be gathered piecemeal from many sources. The additional work entailed in IEMCAP data preparation is converting the data to a computer compatible format. This was not considered to be a significant additional effort by most of the respondents.

There were divided opinions regarding the timeliness of the data. The aircraft people felt that, except for wire-to-wire analysis, there was sufficient data for IEMCAP analysis available by the time of the formal proposal effort (since most projects go into preliminary design one to two years before an RFP actually is promulgated). In the case of wire-to-wire coupling, the routing and bundling designs are not usually available until about one year after contract award. Therefore, for aircraft, the antenna-to-antenna, antenna-to-wire, field-to-wire, and box-to-box analyses can be performed very early in the procurement process and could provide available inputs to the design procedure. This is also probably true for such spacecraft as the space shuttle, although this particular project was not contacted directly.

Most satellite project people were not too concerned with antenna coupled problems. This created major concern for the wire-to-wire case. The wire routing and harness design is not finalized until very late in the design procedure. It was felt however, that each satellite project is sufficiently unique so as to preclude the drawing of general conclusions.

In regard to other required design data it was felt, as in the case of aircraft, that the data was available and that converting it into a computer compatible format was not an effort requiring a significant magnitude of time or money. It was also found that manufacturer's data was not felt to be reliable. There are two kinds of data used, wire data and semiconductor devices operating characteristics data. The latter data is used to determine bandwidth of susceptible circuits. This data was considered a significant source of error by some of the respondents.

These findings were somewhat surprising in that the additional data preparation costs due to using a program such as IEMCAP seemed to be a significant source of objection and consternation at prior IEMCAP presentations. This was not borne out by the interviews. The major difference appears to be the extent to which EMC analysis would be performed, regardless of whether IEMCAP would be available. Those organizations where a thorough effort was planned did not foresee any major additional incremental costs in data preparation. In those organizations where there was a skimpy EMC organization to start with, the additional data gathering costs incurred by requiring IEMCAP was felt to be significant.

4. Utilization of IEMCAP Analysis

There were three major uses determined for IEMCAP analysis. These were in design support, specification support (including waiver and deviation analysis), and test program support. In regard to design support, the primary use is to assist with antenna placement and to highlight the EMC impact of design decisions and changes. In the specification area all the organizations seemed quite wary of using Standard EMC Analysis to tailor

specifications. However, it was unanimously agreed that IEMCAP would be a major tool in waiver and deviation analysis.

The effects on the contractor-subcontractor relationship were discussed at length. One of the matters of interest was the possibility of recovering some costs by relaxing the MIL-STD-461A (or MIL-1541(USAF) for Spacecraft) limits as a result of an IEMCAP analysis. The results of these discussions indicated that significant cost savings would probably not be achieved unless some prior arrangements could be developed during the contract negotiations. For example, the possibility of establishing cost increments during contract negotiations based on ± 20, ± 40, or ± 60 dB changes to the MIL-STD levels was explored. It was felt that this would be difficult to achieve (except for such gross increments as 60 dB) where, for example, the use of shielded cables could be factored in or out as required.

The use of IEMCAP for test planning purposes was thought to be a significant area of possible savings. This would come about through reducing the number of critical circuits to be tested. This opinion was not universally held as there would have to be a high level of confidence in the IEMCAP capability before acceptance of such results. In one case enough confidence was already instilled in the use of an IEMCAP type of program to enable the sponsors to waive test requirements resulting in a significant cost saving. In other cases the only time it was foreseen that test requirements would be reduced was where there were such severe time schedule requirements that all the tests for MIL-E-6051D, for example, could not be accomplished. In all cases it was felt that the ready availability of an IEMCAP-type capability would be welcome and would be exercised provided that the requirements and costs were factored into the project.

5. Specific Comments about IEMCAP

The most commonly voiced problem with the use of IEMCAP was the interpretation and summarization of the output. The use of some type of summary matrix (as is currently being developed by RADC) is thought to be very important. The use of the integrated EMI margin was also questioned. IEMCAP has not been used in any specific project as an integrated capability. Parts of IEMCAP and IEMCAP-type programs (SEMCAP, ATACAP) have been used extensively. Many of the comments are based on these other capabilities. It is significant that specific differences in engineering models between IEMCAP and the other capabilities were not a subject of concern to the respondents.

6. Documenting IEMCAP Requirements and Results

The formal integration of IEMCAP into the procurement process was also a subject of inquiry. The following ideas were discussed.

- Adding an EMC analysis requirement in AFR 800-3.

  The reaction to this suggestion was mixed. Those opposed felt that 800-3 is too high level for such details.

- Changing MIL-STD-1541(USAF) to reflect an EMC analysis requirement.

  This idea is accepted by SAMSO and Aerospace.

- Including IEMCAP in existing CDRL items.

  Some felt that a new CDRL item should be developed. In general, the inclusion in the EMC Control Plan and Test Plan DID's was thought to be sufficient.

- Including EMC analysis in the RFP evaluation criteria.

  This was felt to be very important in providing an incentive to contractor management for early EMC analysis.

The contractor organizations all agreed on the desirability of including the analysis results in the EMC Control Plan. The suggested schedule of running IEMCAP at least four times throughout the project development phase was generally agreed to. The suggested schedule was:

- between Contract Award and Preliminary Design Review (PDR);
- at critical Design Review (CDR);
- between CDR and System Test Plan; and
- at System Test Plan.

It was anticipated that the normal design change process would result in requiring IEMCAP runs an average of every three months.

It was not felt by any of the people contacted that it would be necessary for subcontractors to run IEMCAP. It was also stated that most of the subcontractor EMC Control Plans were "boilerplate" and not worth much. This was not pursued further as it is outside the scope of this study. The important point is that EMC control is imposed by the prime contractor on the subcontractor by controlling the MIL-STD-461A or equivalent limits. This was confirmed by discussions concerning the role of the organizations when they serve as a subcontractor.

One important exception was found on the B-1 program. In this case the electronics package is a subcontract in itself. In such a case the IEMCAP capability could be utilized by such a subcontractor.

7. <u>Additional Uses for IEMCAP Data</u>

The subject of other possible uses for the IEMCAP data base was discussed. The industrial organizations that did not have a wire-tracing or harness routing automated capability thought that such use of the data

base would be a possibility. One area that was unanimously agreed to was the desirability of maintaining the major system data bases throughout the life cycle of the systems. This will result in rapid and economical analysis of modifications.

8. SPO Attitudes Towards EMC

The SPO's that were contacted all evidenced strong support for EMC analysis. One of the major motivations on the part of those most enthusiastic about EMC was prior EMC problems on other projects. This lead to the question of establishing an EMC "lessons learned" file to develop a basis for justifying EMC funding as well as avoiding repetitive problems. There was a definite correlation between the degree of EMC concern and association with past projects where EMC problems had cropped up.

III. THE ECONOMICS OF INTRASYSTEM EMC ANALYSIS

1. Introduction

The economics of Intrasystem EMC analysis concerns a number of factors. Among these are the cost of installing the analysis system, the cost of using the system for a project, the competing costs of manual analysis, and the benefits of utilizing the systems. These factors as well as method of evaluating prediction models in terms of Type I and Type II errors are discussed in this section.

2. General Factors

One of the objectives of this study is to determine cost considerations in using IEMCAP or an equivalent program in a weapon system acqui-

sition program. In order to develop such cost information, the contributing factors have to be isolated.

These are:

(1) the initial cost of installing the program;

(2) any costs of maintaining and updating the program; and

(3) the variable cost of using the program on specific projects including data base preparation and maintenance.

The benefits to be accrued by using the program include:

(1) reduced analysis costs (savings in manpower);

(2) reduced test costs;

(3) possible prevention of retrofit or reduced costs of redesign due to early analysis; and

(4) reduced costs of subsystems and equipment due to the use of tailored specifications.

The study has shown that there is no "typical" system either technically or administratively, but it is nevertheless possible to generate coarse cost estimates.

3. Cost Factors

The costs of acquiring and implementing the program include manpower, training, and computer debugging time. At present these costs range between $1,000 and $15,000 according to industry sources. This depends on past experience of the contractor, internal organization, accounting procedures, etc.

The costs of maintaining and updating the program are difficult to assess since the effort is fairly new. Maintaining and updating costs are those overhead costs incurred in keeping the program current, partici-

pating in liaison activities and meetings, and training and related activities. The program itself, and updated versions, are supplied by the Air Force on tape. This cost is estimated to be zero to $15,000 per year, based on manpower rates and loading factors. In cases of continuous EMC activity on major projects, the overhead costs might be reduced considerably or be nonexistent since the project effort would accomplish these functions.

The cost per project for the additional data preparation and computer running time to use IEMCAP (as opposed to manual analysis) is estimated at $1,000 to $15,000 by industry sources. However, some of these costs are offset by reduced engineering analysis manpower costs. These figures are based on the use of programs similar to IEMCAP.

4. Benefit Factors

The major cost saving factor is the reduction of retrofit and test effort. These savings could be quite substantial. As an example, Westinghouse is developing ALQ-131 pods for use on seven different aircraft. In order to save money, IEMCAP is being used extensively. The savings for an effort of such magnitude as opposed to MIL-E-6051D testing is estimated at $300,000-$500,000 by Westinghouse personnel.

The MINUTEMAN program contains a requirement (MIL-E-6051D) to demonstrate that the weapon system and all associated subsystem/equipment, both airborne and ground, will be capable of performing their intended function without a deleterious impact from the electromagnetic environment. The method of fulfilling this requirement is:

(a) selection of critical circuits by manual analysis;

(b) design and fabrication of sensitized circuits to demonstrate the 6 dB safety margin; and

(c) monitoring weapon systems for failures or anomalies during operation.

A proposed hybrid approach using the SEMCAP program was developed and presented by TRW. This procedure was designed to utilize the analysis program to reduce but not eliminate the test program. An additional benefit of this proposed approach is the savings in time. In the case under discussion, the schedule could not be met by the older test procedure. The cost savings were estimated to be 50% or, for the project under consideration, about $1.5 million. [6]

5. Model Evaluation

Based on these cost factors the answer to the cost-benefit analysis is obvious. Any problem stems from the question of the adequacy in substituting an intrasystem analysis program for system tests. The use of intrasystem analysis programs has been based on the build-up of user confidence over a period of years. This has developed a qualitative level of confidence in these programs on the part of the users. Quantitative assessments of IEMCAP will expedite its use. An RADC sponsored effort to evaluate IEMCAP through its use on the F15 project has lead to such data. Programs conceptually similar to IEMCAP have been applied on large weapons systems. One such program was used on the Navy E-6A project.[1] The results of the analysis of 17,500 possible emitter-receptor combinations are summarized in Table 3 below.

TABLE 3

COMPARISON OF MODEL RESULTS
(Measured/Predicted)

		Measured	
		Interference	No Interference
Predicted:	Interference:	41/71	30/71
	No Interference:	12/17429	17417/17429

An analysis of this table shows that there were 53 interference cases measured, of which 41 were predicted. There were 71 interference situations predicted, of which 30 did not occur. Twelve interference situations occurred which were not predicted. The analysis performed was based on the most detailed models available.

If we define a type 1 error as the prediction of interference when no interference is measured and a type 2 error as the prediction of no interference when interference is measured then:

$$P_e \text{ (type 1)} = 30/71 = .42 \text{ and}$$

$$P_e \text{ (type 2)} = 12/17429 = .00069.$$

If the prediction models are capable of predicting all modes of interference then these errors can be assumed to be independent. In order to reduce the probability of type 2 errors so that virtually all interference cases that are measured have also been predicted, it is necessary to accept a high probability of type 1 errors, i.e. that a considerable proportion of predicted interference will not in fact occur. The exact relationship of these two errors for IEMCAP will not be determined until the program has been exercised on a number of procurements.

One way of looking at such a predicted process is by the use of Bayes Theorem. Let $C_1, C_2, \ldots, C_n$ be mutually exclusive and exhaustive

events and let B be an event for which one knows the conditional probabilities, $P(B|C_i)$ of B, given C_i, and also the absolute probabilities $P(C_i)$. One may then compute the conditional probability $P(C_i|B)$ of any one of the events C_i, given B, by the following formula:

$$P(C_i|B) = \frac{P(B\,C_i)}{P(B)} = \frac{P(B|C_i)P(C_i)}{\sum_{j=1}^{n} P(B|C_j)P(C_j)}$$

This formula is known as Bayes Theorem.

An example of its use could be the following hypothetical situation.[5] Suppose that a test for cancer could be devised where $P(A|C)=.95$, in which C denotes that a person tested has cancer and A denotes the event that the test states that the person tested has cancer. What is $P(C|A)$, i.e., the probability that a person who according to the test has cancer actually has it?

$$P(C/A) = \frac{P(A|C)\ P(C)}{P(A|C)\ P(C) + P(A|C^c)\ P(C^c)^*}$$

Assuming that $P(C) = .005$, i.e., the probability that any person taking the test actually has cancer is .005, then

$$P(C/A) = \frac{.95\ (.005)}{.95\ (.005) + (.05)\ (.995)}$$

$$= .087.$$

Therefore, although the hypothetical cancer test is highly reliable, i.e., it will detect cancer in 95% of the cases in which cancer is present, in only 8.7% of the cases in which the test indicates cancer is cancer actually present.

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*The c superscript indicates the complement of the probability, i.e., the probability of nonoccurrence.

This situation is very similar to that of interference in an aircraft as discussed above. If we let M represent measured interference and P represent predicted interference then, using the model discussed, the probability that interference will not be measured where it is not predicted is:

$$P(M^c | P^c) = .99931$$

or the model is 99.93% effective in screening interference. However, the probability that interference will be indicated by measurement in cases where it is predicted is:

$$P(M | P) = .58$$

or, in only 58% of the cases where interference is predicted will such interference actually be measured. In terms of type 1 and type 2 errors, assuming that measured data represents the real world, the probability of type 1 error is:

$$P(M^c | P) = .42$$

and for type 2:

$$P(M | P^c) = .00069.$$

While this description of the model indicates high reliability, an objective evaluation requires the consideration of cost data. If the major savings have to do with reduction of test costs, even further reduction of the type 2 error is required. This will cause an increase in type 1 errors. The results of the model described, in the terminology defined, are:

$$P(P | M) = .774$$

or only 77% confidence that all the interference cases measured would be contained in the prediction. If it is desired that the model only miss one case that actually occurs in the situation described the probability of a type 2

error $P(M|P^c)$ would have to be reduced to .000057 from .00069. The resultant confidence level that all the interference cases would be included in the predicted data would be .98. Actual data would be required to determine the effects on the type 1 error.

Further pursuit of such model evaluation is indicated. It is important to note that most model evaluation is done using a comparison of measured and predicted values (usually in dB). This is an important factor but only an intermediate step. The results of the use in the model in the specific project and its impact in terms of dollars goes beyond dB comparisons. In other words, if the payoff is in reducing test costs (as it appears to be at this point), the dB bias that would have to be introduced to provide acceptable confidence levels would be large. This dB bias would also assure that there would be large errors in the predicted vs. measured data comparisons if these are based on dB levels.

Examples of typical results of such comparisons are contained in figures 1 and 2 [7]. These results are based on SEMCAP prediction data. The figures show the comparison of measured vs. predicted data for two spacecraft. The first figure shows a correlation diagram in dB, and the second a correlation diagram in voltage with a 6 dB and a 20 dB bias. Note that 20 dB would be required to encompass all the points.

6. IEMCAP Implementation Criteria

Criteria are standards, rules or tests by which a decision is made. The criteria required for the effort determining the best way to implement IEMCAP fall into two categories: criteria for determining the use of IEMCAP on projects (Which projects should it be applied to? When should it be used?) and criteria for determining which documents should be used to create the requirement for using the analysis program.

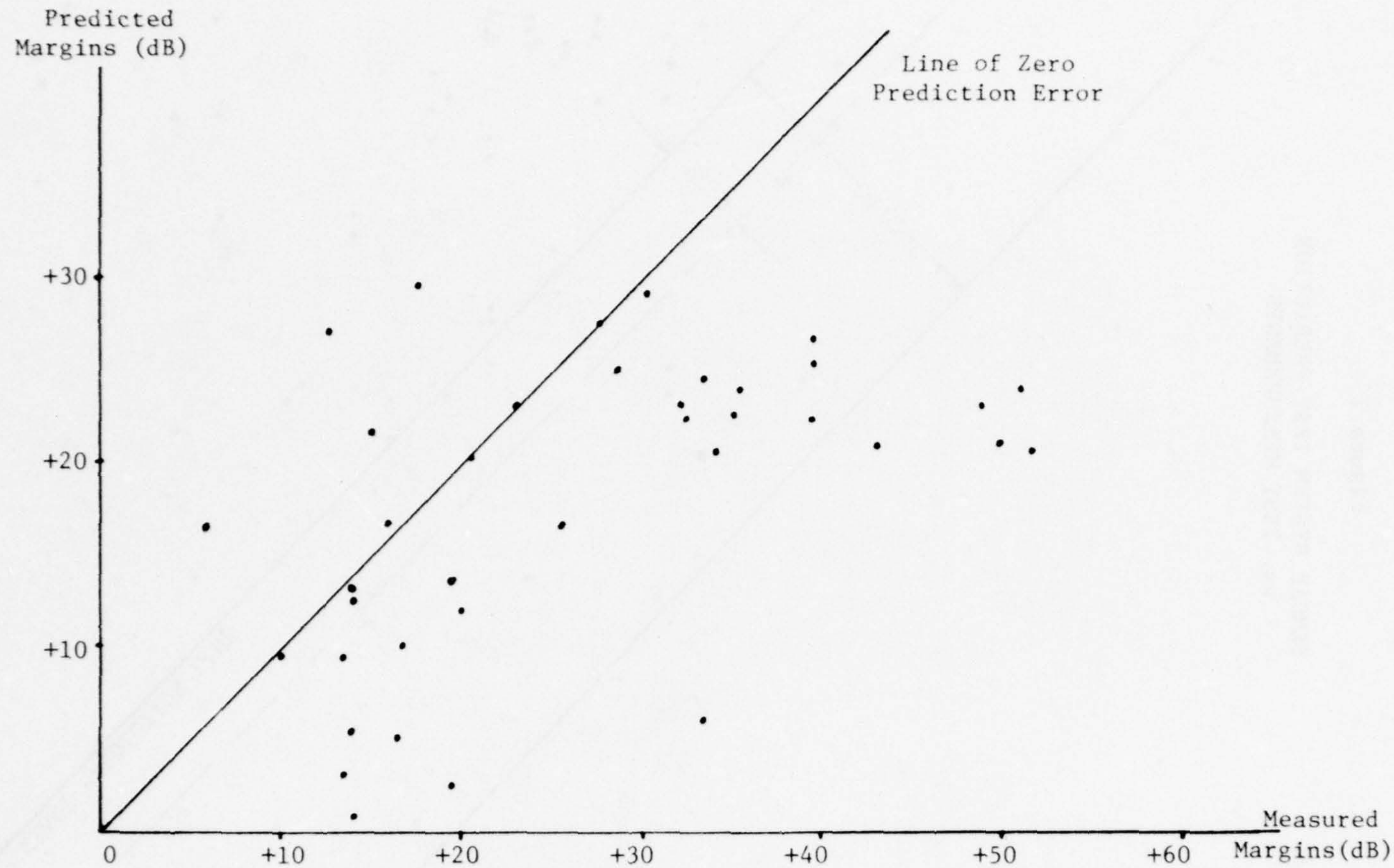
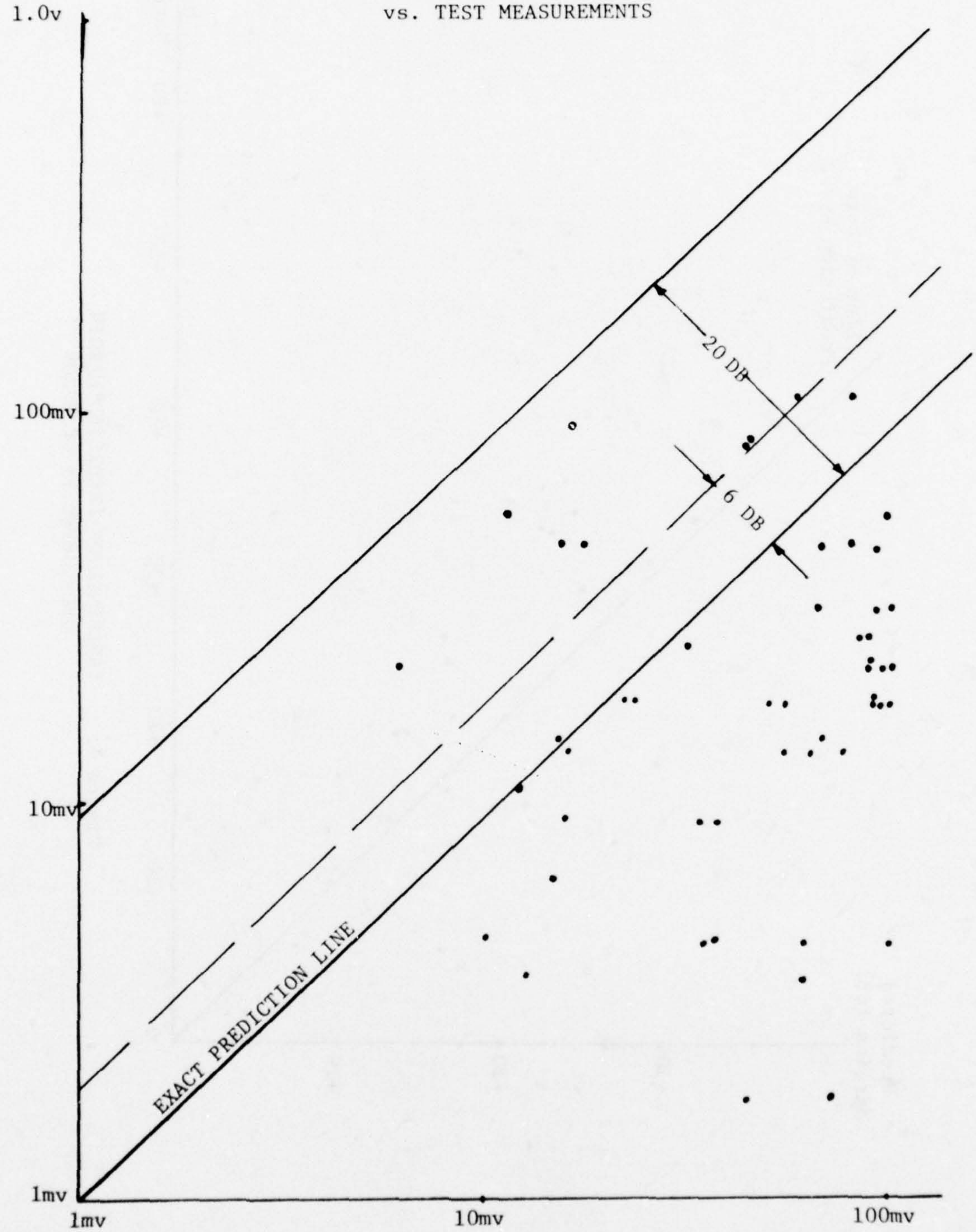


Figure 1: INFLUENCE OF PREDICTED MARGIN UPON SEVERITY OF ERROR

Figure 2

SEMCAP SYSTEM TEST PREDICTION
vs. TEST MEASUREMENTS



Criteria are also separable into the following three categories:

(a) characteristics to be achieved;

(b) characteristics to be preserved; and

(c) characteristics to be avoided.

The establishment of these criteria is in terms of specific parameters including costs and impact on the procurement process.

Implementation on Projects

The utilization of IEMCAP from a cost analysis viewpoint is heavily weighted towards its use on the basis of possible test savings alone, not including the savings to be realized by reducing the engineering analysis manpower requirements. The present obstacle to realizing these savings is the confidence one can expect from the use of IEMCAP. This is expected to be resolved with time as results become available.

The criteria for the implementation of the IEMCAP capability on a system should consider some minimum size, since it is obvious that there is a point of minimum system size at which the use of manual analysis is less expensive than the cost of installing and running the IEMCAP system and preparing a data base. The IEMCAP system is provided at no cost to the contractor. The cost of computer time for a single computer run for a large system is on the order of \$250 - \$1000. The cost of data preparation is only the cost involved in taking the data from a "raw" format to a computer compatible medium, since the data has to be available for manual engineering analysis as well although not in a rigidly controlled format.

The break-even point is therefore the point at which the cost of computer running time plus program-required data conversion costs equal the cost of manual engineering analysis. The loaded cost of manual engineering analysis is about \$200 per man-day. The cost of data preparation for computer

input is about \$100 per man-day. Assuming a minimum of four runs (about \$1000 - \$4000), the break-even point is reached for a system that requires about 1 to 4 man-weeks of manual engineering analysis.

There are other possible advantages to using IEMCAP as well as cost. The use of a standard method of automated analysis assures reproducibility of results, a standard data base, and a standard output format. Therefore, IEMCAP should be applied at the minimal system level. Since there is no direct cost data for IEMCAP, a preliminary criterion of 100 or more possible coupling paths is considered appropriate (based on the 1 to 4 man-week engineering manpower figure derived above).

Implementation in Documents

The criteria to be used in establishing the documentation requirements including achieving IEMCAP use on all appropriate system procurements, preserving the present system of contractual documentation, and avoiding unnecessary additional documentation or new CDRL items. This last criteria may be achieved by integrating the requirements into existing documents. The orientation of IEMCAP towards systems requires some definition of a system from an EMC standpoint. The most straightforward definition is that an appropriate system consists of two or more electrical or electronic subassemblies organized to perform a specific function.

The decision as to which of the documents should be modified also requires consideration of the specific discipline (EMC analysis) and the level of the document. For example, in the case of MIL-STD-499, the level is felt to be too high to include a discussion of the type of EMC analysis to be used. In most cases the documents reference each other. In order to avoid extraneous difficulties or redundancy, a hierarchy of requirements can be established. This hierarchy would handle such cases where, for example, a

primary source, i.e., MIL-E-6051D, is referenced in a group of DID's. By adhering to the hierarchy the change would be made to the specification and would automatically be integrated in the procurement process. The specification could be referred to as a primary source document.

In summary, the basic criteria to be used in determining the documentation requirements are:

(a) current documents;

(b) EMC analysis;

(c) appropriate level of detail;

(d) system oriented; and

(e) primary sources.

A review of the documents listed in Table 4 was performed. The results of applying the above criteria to determine which of these documents should be changed are reflected in that table.

IV. CONCLUSIONS

1. Corporate Management Support

The management support for using IAP in the corporate EMC cycle is almost exclusively based on contractual obligations and funding. There is presently a broad acceptance of the results of IAP type analyses for decision making purposes. The situation might change, however, if the results of using IAP do not represent a positive improvement in the intrasystem EMC process.

2. Contractor Staff Support

The efficiency of the use of IAP is a direct function of the experience and training of the contractor staff. Due to the stop and go

TABLE 4

Data Item Descriptions	DOCUMENTS	MODIFY	CRITERIA
Category II Test Plan Procedures	DI-T-3706/T-106-2	No	3
General Test Plan Procedures	DI-T-3707/T-107-2	No	3
Test Reports - General	DI-T-3718/T-119-2	No	3
Category II Test Reports	DI-T-3719/T-120-2	No	3
Acceptance Test Reports	DI-T-3721/T-125-2	No	3
Engineering Change Proposals	DI-E-3128/C-141-1	No	3
Request for Deviation/Waiver	DI-E-3129/C-142	No	3
Electromagnetic Compatibility Plan	DI-R-3530/S-116-1	No	5 (References MIL-E-6051)
Subsystem Design Analysis Report	DI-S-3581/S-101-1	No	3
Category I Test Plans/Procedures	DI-T-3702/T-102-2	No	3
Electromagnetic Compatibility Test Plan-Systems and Subsystems/Equipment	DI-T-3704/T-104-2	No	

Specification/Standards	MODIFY	CRITERIA
MIL-STD-461, Electromagnetic Interference Characteristics Requirements for Equipment	No	4
MIL-STD-462, Electromagnetic Interference Characteristics, Measurement of	No	4
MIL-STD-463, Definitions and System of Units, Electromagnetic Interference Technology	No	4
MIL-STD-469, Radar Engineering Design Requirements Electromagnetic Compatibility	No	4
MIL-STD-480, Configuration Control	No	3
MIL-STD-481, Configuration Control (short form)	No	3
MIL-STD-482, Configuration Status Accounting	No	3

TABLE 4 (Continued)

DOCUMENTS	MODIFY	CRITERIA
Specification/Standards (Cont'd)		
MIL-STD-490, Specification Practices	No	3
MIL-STD-499, System Engineering Management	No	3
MIL-STD-721, Definition of Effectiveness Terms	No	3
MIL-STD-833, Minimization of Hazards of Electromagnetic Radiation to Electro-explosive Devices	No	3,4
MIL-STD-881, Work Breakdown Structures	No	3
MIL-STD-882, Safety Engineering	No	3
MIL-B-5087, Bonding, Electrical, and lighting Protection, for Aerospace Systems	No	3,4
MIL-STD-1541 (USAF) EMC Requirements for Sapce Systems	Yes	
MIL-W-5088, Wiring, Aircraft, Installation of	No	4
MIL-E-6051, Electromagnetic Compatibility Requirements, System	Yes	
Manuals/Handbooks		
AFM-100-31, Frequency Management and Electromagnetic Compatibility, 13 Mar 1970; Change 1, 22 Dec 1970; Change 2, 2 May 1972; Change 3, 31 Oct 1972	Yes	
AFSCM 70-5, Work Statement Preparation	No	3
AFSCM 207-1, Security Engineering	No	3
AFSCR 310-1, Management of Contractor Data & Reports	No	3
AFSCM 375-1, Configuration Management	No	1,3
AFSCM 375-3, System Project Office (SPO) Manual	No	1,3
AFSCM 375-4, System Program Management Procedure	No	1,3
AFSC Design Handbook 1-4, Electromagnetic Compatibility	Yes	
AFSC Design Handbook 2-5, Armament	No	3,4

TABLE 4 (Continued)

DOCUMENTS	MODIFY	CRITERIA
Regulations		
AFR 80-2, Documents Used in the Management of Air Force Research Development	No	3
AFR 65-3, Configuration Management	No	3
AFR 80-20, Concept Formulation and Contract Definition	No	1,3
AFR 80-23, The U.S. Air Force Electromagnetic Compatibility Program	Yes	
AFR 100-2, Ground Communications Electronics Meteorological (CEM) Planning and Programming	No	3
AFR 100-3, Electromagnetic Compatibility Program-Reporting of U.S. Military Electronic Equipment Environmental Data	No	4
AFR 100-4, Radio Frequency Management	No	1,3
AFR 100-6, Electromagnetic Interference and Radiation Hazards	Yes	
AFR 375-1, Management of Systems Program	No	1,3
AFR 375-2, System Program Office	No	1,3
AFR 375-3, System Program Director	No	1,3
AFR 375-4, System Program Documentation	No	1,3
AFSCR 80-23, Research and Technology Assistance to Systems Program	No	3
AFSCR 800-2, Management of Multi-Service System, Programs and Projects	No	3
AFSCP 800-3, A Guide for Program Management	Yes	
AFSCM 375-7, Configuration Management	No	3

nature of EMC project funding, staff continuity was found to be lacking in some cases. It appears that this will be a chronic condition and will require frequent presentation of training courses, assistance, and simplified running procedures and data outputs.

3. Early Data Availability

The input data required for IEMCAP and other components of IAP is available early in the life cycle. The data is usually developed in design activities prior to any formal EMC activity. The major exception is wire routing and bundling data. This problem can be tolerated until the design is finalized by the use of estimates.

4. IAP Cost-Beneficial for Use in System Test Planning

System tests, such as those in MIL-E-6051D, are costly and time-consuming. Automated intrasystem analysis has demonstrated the ability to save considerable funds by reducing the required number of tests and time required for testing. This area of utilization apparently represents the greatest potential for cost savings.

5. Specification Tailoring

Tailoring of specifications on the basis of IAP results is a generally accepted goal but one that must be approached with caution. The addition of a validation phase to the LCSMM has somewhat mitigated the urgency and importance of absolute accuracy in specification tailoring. Potential cost savings can be validated on prototypes prior to large production commitments. The combination of analysis, testing and specification tailoring, based on the overall results, represents a systematic approach to cost savings and EMC achievement.

6. Contractor/Subcontractor Relationships

IAP should be used only at the prime contractor level except in rare instances (such as the B-1) where the entire avionics package is a subcontract. It appears that the tailoring of specifications for subcontract items is not highly critical in regard to cost savings. However, the use of IAP to determine the impact of waivers or deviations provides an important capability and is expected to be of great assistance in project management. The use of different cost estimates based on tailoring the specifications by increments (such as $\pm$20dB, $\pm$40dB, $\pm$60dB, etc.) does not seem to be feasible in most cases. This is due to the inability to accurately estimate cost differences except for the most gross changes (such as 60 or 80dB).

7. IAP Central Facility

It is apparent that a permanent central facility is required to provide intrasystem analysis program support to the project management community. Among the reasons for this requirement are the needs for continual updating of the IAP itself, liaison and training of users, data base standardization and storage for systems throughout the phases of the LCSMM and the gathering, analysis, storage and dissemination of experiential data concerning system problems and the IAP itself. Only a centralized facility could efficiently function in such a capacity.

8. Documentation Changes

The proper utilization and funding of IAP project support requires a basis in regulations, specifications and other documentation. There is no basic user guidance document available. The suggested changes and a handbook are appended to this report. The need for an SPO EMC Program

Plan for large projects is also evident.

9. Schedule for IAP

The major purpose for IAP is to support the project. In order to optimize that support the scheduling should be flexible. A suggested minimum for IAP runs is at times of:

(a) EMC Control Plan development;

(b) Preliminary Design Review (PDR);

(c) once at an intermediate time between PDR and Critical Design Review (CDR);

(d) CDR; and

(e) system test planning.

10. Minimum Size Project for IEMCAP

The question of the minimum project size for requiring IEMCAP support from a cost standpoint is difficult to answer since there are low cost systems that can have severe and significant EMC problems while certain high-cost systems can have virtually no EMC problem potential. The cost trade-off curve based on analysis costs indicates that systems where there are 100 or more interactions (combinations of emitter and receptor ports) justifies the utilization of IEMCAP. The other components of the IAP have not been similarly evaluated.

11. The Impact of IEMCAP on the Negotiation Process

One major item of study in this investigation was the potential impact on Government/Contractor/Subcontractor Contracting relationships of the use of IEMCAP for tailoring specifications. The major basis for this consideration is the often-expressed question of how to enter into a contract

without strictly defined specifications. The major area affected on large system procurements is the contractor/subcontractor relationship. The primary EMC control on the subcontractor is usually MIL-STD-461A. Financial commitments between the contractor and the subcontractor are necessary at the time a system proposal is submitted and, although tailoring of the specification can be done at that time, the EMC data base is usually not sufficient to perform a detailed analysis. One way to get around this problem is to request alternate bids for items meeting the specification with 20, 40 or 60dB variations. The study has shown that such costs, except for very large EMC Specification differences (on the order of 60dB) are difficult to determine. It also shows that the cost variations would be minor when compared with the total item cost.

Therefore, it appears that some tailoring can and should be done at the earliest phase of the procurement. This will not, however, obviate the need for waivers and deviations and consequent waiver and deviation analysis. The impact of IEMCAP on this contractor/subcontractor relationship will not be to materially affect the present negotiating regime, but to offer more technical substance as a basis for decision as it progresses.

V. RECOMMENDATIONS

1. ICAP Facility

The conclusions of this study clearly indicate that a central USAF intrasystem analysis support facility is needed. It is therefore recommended that such a facility be established at RADC. The IAP development effort is currently being performed there and a great deal of the effort will concern long-term modification, refinement and general updating of the codes. Training programs and a newsletter have also been developed. This form of

activity appears to be a continuing requirement. A central data base repository will be required as the data bases for projects are developed and the systems progress through their life cycle. The results of the application of IAP to projects should be evaluated and the lessons learned should be compiled.

2. Project Management EMC Handbook

The attached draft of the Project Management EMC Handbook should be circulated. Comments should be solicited and modifications made as appropriate. This process should continue as the EMC techniques are introduced and their impact observed.

3. Documentation

The integration of IAP into the systems development and procurement process requires that the following documents be modified as recommended below.

(a) AFM 100-31 Frequency Management and Electromagnetic Compatibility (Chapter 4)

"4.10 Intrasystem Analysis. Rome Air Development Center has developed an Intrasystem Analysis Program (IAP) for use by contractors in system development. Components of the system include:

a. IEMCAP;

b. a series of supplemental models (for use in conjunction with IEMCAP) that provide additional analysis for aircraft stores, lightning, magnetospheric substorms, and static electricity; and

c. nonlinear and EM/near-field analysis models which will characterize the input/output relation of nonlinear circuits, EM/near-field interactions, and antenna and aperture coupling

being developed for off-line use.

The programs are available to Air Force contractors. Training courses are presented periodically. Schedules and further details can be obtained through RADC/RBC.

4.11 IEMCAP (Intrasystem EMC Analysis Program)

The Intrasystem Electromagnetic Compatibility Analysis Program (IEMCAP) was designed to provide an effective and cost beneficial means of EMC analysis throughout the stages of an Air Force system's life cycle, from conceptual studies of new systems to field modification of old systems. Ground, aircraft, and space/missile systems are within the IEMCAP capability. The program is relatively computer independent and has been implemented on several computers. It is programmed in USA standard FORTRAN IV language and requires approximately 70K words of core.

IEMCAP analysis demonstrates the relationship between equipment and subsystem EMC performance and total system EMC characteristics in specific terms. It therefore provides the means for tailoring EMC requirements to the specific system. This is accomplished by modeling the system elements and the mechanisms of electromagnetic energy transfer to accomplish the following tasks:

a. provide a data base that can be continually maintained and updated to follow system design changes;

b. generate EMC specification limits tailored to a specific system;

c. evaluate the impact of granting waivers to the specifications;

d. survey a system for incompatibilities;

e. analyze the effect of design changes on system EMC; and

f. provide comparative analysis results on which to base EMC trade-off decisions.

4.12 IEMCAP Operation. The Input Decode and Initial Processing Routine (IDIPR) is the first part of IEMCAP. It is divided into three basic routines. The Input Decode Routine (IPDCOD) reads and decodes the free-field input data from punched cards and checks the data for errors. Next is the Initial Processing Routine (IPR). This routine performs data management, interfaces with spectrum models, and generates the working files. The data base defining the system/subsystem/equipment characteristics is stored on a magnetic disc or tape called the Intrasystem File (ISF). The program then enters the Wire Map Routine which generates cross-reference map arrays for use by the wire coupling math models during analysis. At this point, execution of IDIPR terminates.

The second section of IEMCAP, called the Task Analysis Routine (TART), uses the data compiled by IDIPR to

perform one of the four analysis tasks listed below.

a. Specification Generation - This subroutine adjusts, within specified limits, the initial non-required emission and susceptibility spectra, attempting to make the system compatible. A summary of interference situations is printed.

b. Baseline System EMC Survey - The subroutine analyzes the system for interference. If the maximum of the EMI point margins over the frequency range for a coupled emitter-receptor pair exceeds the user specified printout limit, a summary of the interference is printed. Total received signal into each receptor from all emitters is also printed.

c. Trade-Off Analysis - This subroutine compares the interference from two EMC analysis runs. The effect on interference of antenna changes, filter changes, spectrum parameter changes, wire changes etc., can be assessed from this analyses.

d. Specification Waiver Analysis - This subroutine allows adjustments to selected port spectrums (often to represent a waiver request) and evaluates the impact of this change."

(b) AFR 80-23, USAF Electromagnetic Compatibility Program (Paragraph 14)

"a. Emphasize EMC in the design and development of electrical and electronic equipment (see AFR 57-1, AFR 80-2, and AFR 800-2) for policy on the management of design and development. This includes the required use of the Air Force developed Intrasystem Analysis Program (IAP) or equivalent mathematical modeling techniques to analyze system EMC during the design, development and production of systems, subsystems, and equipments."

(c) AFR 100-6 Electromagnetic Interference and Radiation Hazards (Paragraph 6, AFSC Responsibilities)

"K. Provides, through RADC/RBC, intrasystem EMC analysis support and technical assistance on related problems."

(d) AFSCP 800-3, A Guide for Program Management

1. Paragraph 8-21, Electromagnetic Compatibility (EMC):

Subparagraphs: a.(2) AFDL should be AFFDL

a.(4) ENAEA should be ENAMA

a.(6) Change to: "Exploratory development in all facets of EMC and intrasystem EMC analysis and modeling."

2. Add to Subparagraph 8-21.b.:

"The utilization of the Intrasystem Analysis Program (IAP) for the purposes of EMC analysis, determining the effects of waivers and deviations, tailoring EMC specifications and standards, identifying possible EMC problem areas for test planning and general EMC support is required. The Air Force has developed this capability as a family of computer programs for use by Air Force contractors. These are available through RADC/RBC."

(e) MIL-E-6051D, Electromagnetic Compatibility Requirements, Systems

1. Add to paragraph 3.2:

M. Mathematical modeling.

2. Add:

3.2.16 Mathematical Modeling. Mathematical modeling shall be used to analyze the system EMC during the design, development, and production of systems, subsystems, and equipments. The objectives of this modeling are to optimize design, predict and solve potential EMI problems, and tailor EMC requirements and testing. Mathematical models of sufficient scope and accuracy shall be used to achieve these objectives. Where applicable, these models shall describe antenna-to-antenna, wire-to-wire, and external field-to-wire coupling modes. Environmental sources such as lightning and precipitation static shall also be described. Whenever possible, computer-implemented models such as those of the Air Force Intrasystem Analysis Program shall be used.

3. Add to paragraph 3.3:

W. Application of mathematical modeling throughout the phases of design, development, and production.

4. Add to paragraph 4.2:

   5. Results of the application of mathematical modeling techniques in developing the test program.

(f) Air Force Design Handbook DH1-4

The changes to DH1-4 have been developed and reviewed by ASD and are presently being incorporated in the handbook.

(g) MIL-STD-1541 (USAF) Electromagnetic Compatibility Requirements for Space Systems

Appropriate changes to MIL-STD-1541 have been developed by SAMSO and are being incorporated.

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